Sediment Transport in the Eel River Plume

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LONG-TERM GOAL

My long-term goal is to understand the mechanics of river-plume transport of sediment and its influence on the trapping and dispersion of sediment on the continental shelf. This effort will also contribute to the development of predictive models of sediment dispersal and sedimentary strata formation.

OBJECTIVES

I set out to determine the trajectory and fate of suspended sediment entering the Pacific Ocean from the Eel River, Northern California, during floods. The initial hypothesis was that sediment was delivered directly to the mid-shelf flood deposit, at water depths between 60 and 90 m, via hemipelagic deposition from the surface plume. In order to test this hypothesis, measurements of the river plume had to be obtained during flood conditions, to determine the influence of the unique forcing conditions during storms on the plume trajectory and sediment transport.

APPROACH

I arranged with the US Coast Guard Group Humboldt Bay to fly hydrographic survey missions during floods of the river. Flights would be scheduled with as little as 2 hours notice, based on the stage of the Eel River. Several flights were performed during a minor flood in December, 1996, and 4 flights were performed during an extreme flood event on December 30, 1996 - January 3, 1997. Nine flights were performed during the winter of 1997-1998, responding to a sequence of significant floods associated with the El Niño conditions on the West Coast. The duration of the flights was 1.5-2 hours. Up to 15 vertical profiles were obtained on each flight, lowering the instrument package using the helicopter's hoist. The instrument package includes two self-triggering water samplers, a temperature-salinity-depth recorder (CTD) with an optical backscatterance sensor (OBS), and a particle-imaging camera. During the 1998 measurements, the profiles extended to the seabed, providing bottom boundary layer measurements in addition to the plume measurements. Water from the samplers was filtered to obtain suspended solids measurements for calibration of the OBS.

Moorings were deployed over the inner shelf in 1996-1997 and 1997-1998, to provide timeseries measurements to complement the helicopter surveys. These moorings included near-surface current measurements, salinity, temperature, and optical backscatterance.

A 3-dimensional numerical model was used to simulate the plume structure and to determine the influence of different forcing variables on the trajectory of suspended sediment. The Princeton Ocean Model (POM), a popular model for simulating coastal environments, was used for this project. The

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simulations focussed on the major flood of January, 1997. By varying the forcing conditions and details of the model domain, I have investigated the relative importance of winds, tides, freshwater outflow, and geometry of the river mouth region on the structure of the plume and the fate of the sediment. I have also looked at the dynamics of the plume, to determine the dominant physical processes controling the structure and motion of the plume.

WORK COMPLETED

The data from the rapid-response surveys during 1996-1997 and 1997-1998 has been processed and analysed, and analysis of the timeseries data is well underway. All of the water samples have been filtered and weighed, and the OBS sensor has been calibrated.

The numerical model is operational, and I have performed approximately 20 runs to explore the sensitivity to different forcing conditions and to examine the detailed dynamics of the plume. A realistic grid has been developed, and I am just beginning to implement realistic simulations.

RESULTS

The most important result of the Rapid Response study is our observation that the plume is much narrower than the offshore position of the flood deposit. During the major flood of 1997, the plume only extended out as far as the 40-m isobath, whereas the flood deposit lay between the 60- and 90-m isobaths. This indicates that the sediment is not delivered directly to the flood deposit, but instead it must follow a more complex trajectory. The sediment rains out of the plume over the inner shelf, where it forms a temporary deposit for days to weeks. Subsequent resuspension due to waves and currents remobilizes the sediment, and it is transported seaward to the mid-shelf flood deposit. The mechanisms of offshore transport are still unknown and represent a major focus of my future STRATAFORM research.

The physical processes responsible for the anomalously narrow plume were investigated with numerical model simulations. A number of factors were all found to be important, including along-coast wind stress, ambient, along-shelf current, and river mouth geometry. The last variable was a surprise, because we did not expect that the details of the near-field mouth conditions could have a significant impact 15-30 km downstream. However, the large inertia of the outflowing river is a dominant contributor to the momentum balance of the plume. Thus, the direction of that momentum is a critical determinant to the cross-shelf transport by the plume. Videos obtained during the aerial surveys were analyzed to determine the angle of the mouth relative to the shore. The river enters nearly tangentially to the shore, at a 15 degree angle to the trend of the coast. The momentum of the river is thus directed mostly along-shore, rather than cross-shore, preventing significant offshore spreading of the plume.

Another important discovery was the variation in suspended load within the plume, which may indicate large variations in particle aggregation dynamics through the course of flood events. During strong downwelling conditions (i.e., southerly winds), the suspended sediment behaved nearly conservatively within the plume, indicating very low settling velocities (<0.2 mm/s). During weak, upwelling winds, the suspended sediment was distinctly non-conservative, indicating significantly larger settling rates (>0.5 mm/s). The variation in settling velocity may be explained by variations in particle size due to variations in turbulent intensity. This hypothesis is presently being explored by Hill, Milligan and me.

The detailed examination of plume dynamics in the numerical model is revealing a complex cross-shelf circulation regime within and beneath the plume. The momentum of the plume is an important driving variable, as is Ekman transport and density-driven, cross-shelf motions. An important set of issues that this investigation raises is how sediment is trapped beneath the plume, and how that sediment is remobilized and transported to the flood deposit.

IMPACT/APPLICATION

The results of the Rapid Response plume study have forced a major revision in the conceptual model of how flood deposits form on the Eel Shelf. The processes being observed here probably find broader relevance to river systems with narrow, mountainous drainage basins (as characteristic of most of the Pacific Rim). The trajectory of a river and its associated sediment cannot be ascertained by considering only the climatological conditions; instead, the conditions occurring during discharge event have to be considered in conjunction with the sediment discharge. The tight coupling of the modeling in this study with observations provides more detailed insights into the processes than could be obtained without the combination, and it provides the most effective path toward a predictive modeling capability for coastal environments.

TRANSITIONS

I am working closely with Hill and Milligan on coupling the physical processes with the particle aggregation processes, both in terms of data analysis and modeling. I am also working with Wiberg and Harris to incorporate their boundary layer modeling technique into the 3-d model. I have communicated the key observed features and dynamical processes of the plume to Morehead and Syvitski, which should help keep their plume modeling efforts on track. I am also working with Lynch and Traykovski on the mechanisms of offshore transport in the bottom boundary layer.

RELATED PROJECTS

I am involved with a study of plume dynamics as it relates to harmful algal blooms in the Gulf of Maine, in collaboration with Don Anderson (WHOI) with funding from NOAA and NSF as part of the ECOHAB project. A student of mine named Derek Fong just finished his dissertation with support from this project. The thesis considers the dynamics of wind-forced river plumes.